



# The JPSS CrIS Instrument and the Evolution of Space-Based Infrared Sounders

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## **Infrared sounder evolution since the 1970s**

### **Cross-track Infrared Sounder (CrIS) on Suomi National Polar-orbiting Partnership (SNPP)**

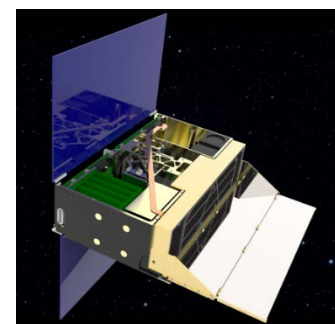
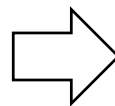
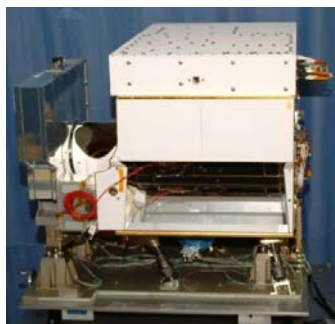
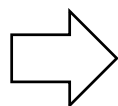
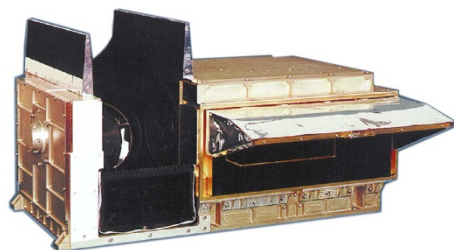
#### **CrIS on Joint Polar Satellite System-1 (JPSS-1)**

- Improvements over CrIS SNPP
- Measured performance during ground test
- On-orbit status

#### **Production status of CrIS instruments for JPSS-2 through JPSS-4**

#### **New technologies for future infrared sounders**

#### **The expanding usage of infrared sounding data**



# Filter Wheel Sounders (1970s to Present)

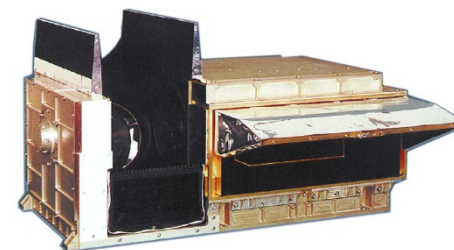


## First generation of sounders used multiple spectral filters in a rapidly spinning wheel

- ~20 filters spanning Visible through Long Wave Infrared (LWIR)
- Technical challenges overcome
  - Lifetime of filter wheel mechanism
  - Very fast readout of detectors to achieve reasonable spatial coverage
  - Achieving adequate Signal-to-Noise (SNR) with short integration time per band

## NOAA/NASA explored hyperspectral versions of both instruments during the 1990s

- “HIRS Hybrid” and “GOES High-resolution Interferometric Sounder”
- Both were interferometer-based
- Neither reached flight status



### High-resolution Infrared Radiation Sounder (HIRS)

- 20 channels
- 10 km spatial resolution
- First Launch: 1972
- 12 units flown



### High-resolution Infrared Red Sounder (HIRS)

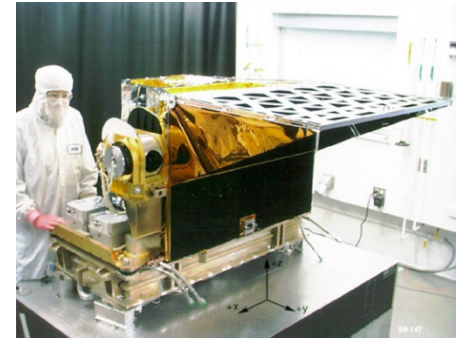
- 19 channels
- 8 km spatial resolution
- 8 units flown

# First Hyperspectral Sounders: AIRS and IASI



## Atmospheric Infrared Sounder (AIRS): 2002-Present

- World's first hyperspectral sounder
- Validated the improvement in sounding quality due to large number of channels
- Dispersive spectrometer, active cooling
- Still operating well past required mission life



### AIRS

- 2378 channels
- 13.5 km spatial resolution
- Launched in 2002

## Infrared Atmospheric Sounding Interferometer (IASI):

- Contiguous spectral range (no gaps)
- Finer spectral resolution enables trace gas detection
- Interferometric spectrometer, active cooling

## Both instruments are relatively large with considerable power consumption

- Design goal for CrIS: smaller size and power

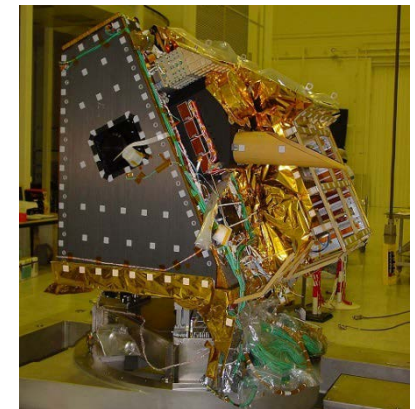


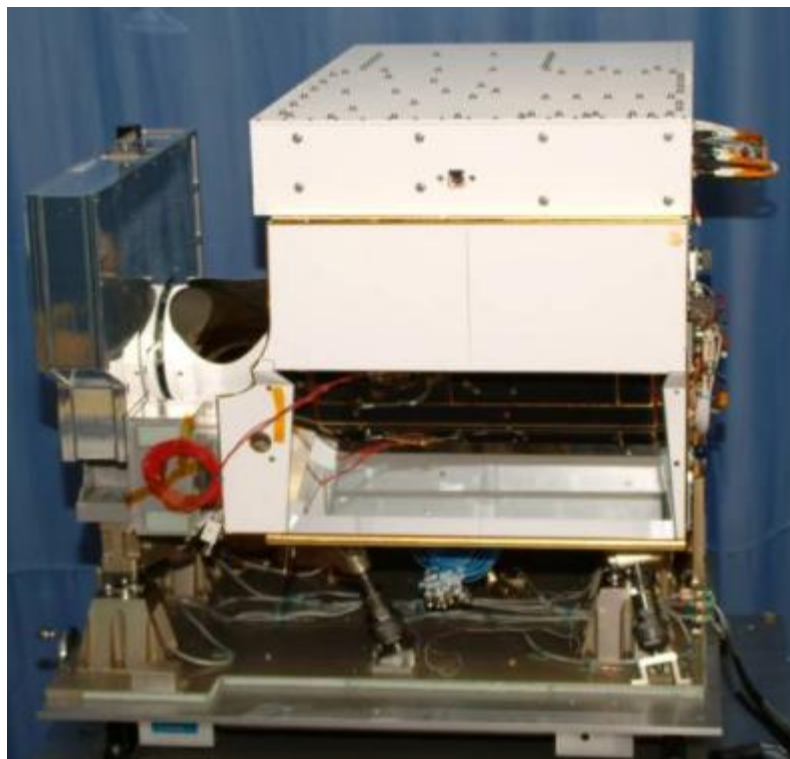
Photo Courtesy of Alcatel

### IASI

- 8461 channels
- 12 km spatial resolution
- 2 units in orbit



# CrIS: Designed for Compact Size, Optimum LWIR NEdN, and Superb Calibration



## • Innovative CrIS Features

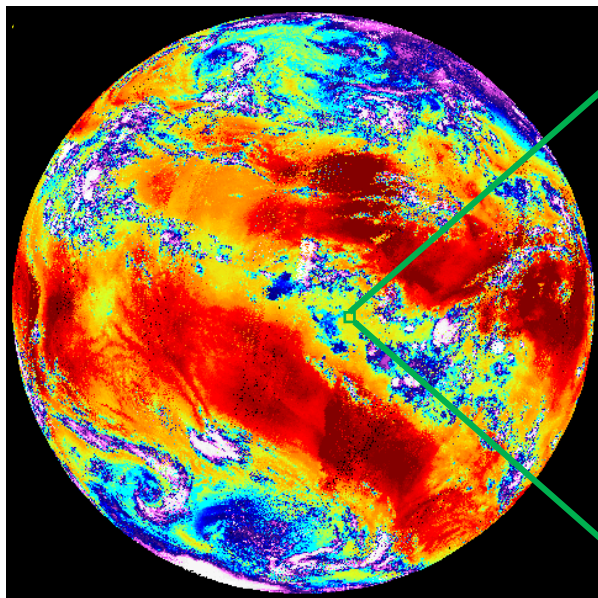
- Passive detector cooling to minimize power consumption
- Compact packaging for small size and mass
- Low noise levels (NEdN) enabled by 8cm aperture and low-noise FPAs / electronics
- Extremely stable radiometric response, enabled by low-drift electronics and optical stability
- Precise radiometric calibration enabled by high-quality calibration target and frequent calibration looks
- Spectral accuracy maintained using onboard neon calibration sources

Band	Wavelength Range		Sampling (cm <sup>-1</sup> )	No. Chan.
	(cm <sup>-1</sup> )	(μm)		
SWIR	2155-2550	4.64-3.92	0.625	633
MWIR	1210-1750	8.26-5.71	0.625	865
LWIR	650-1095	15.38-9.14	0.625	713

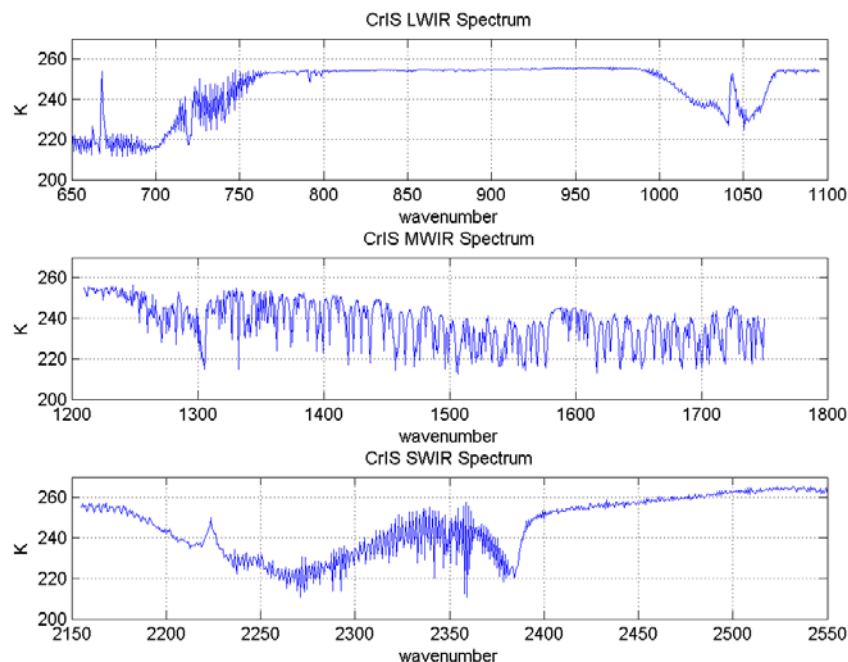
**Total Channels = 2211**

Mass	Power	Volume
146 kg	105 W	~0.4 m <sup>3</sup>

# The Extraordinary Data Content of Hyperspectral Sounders

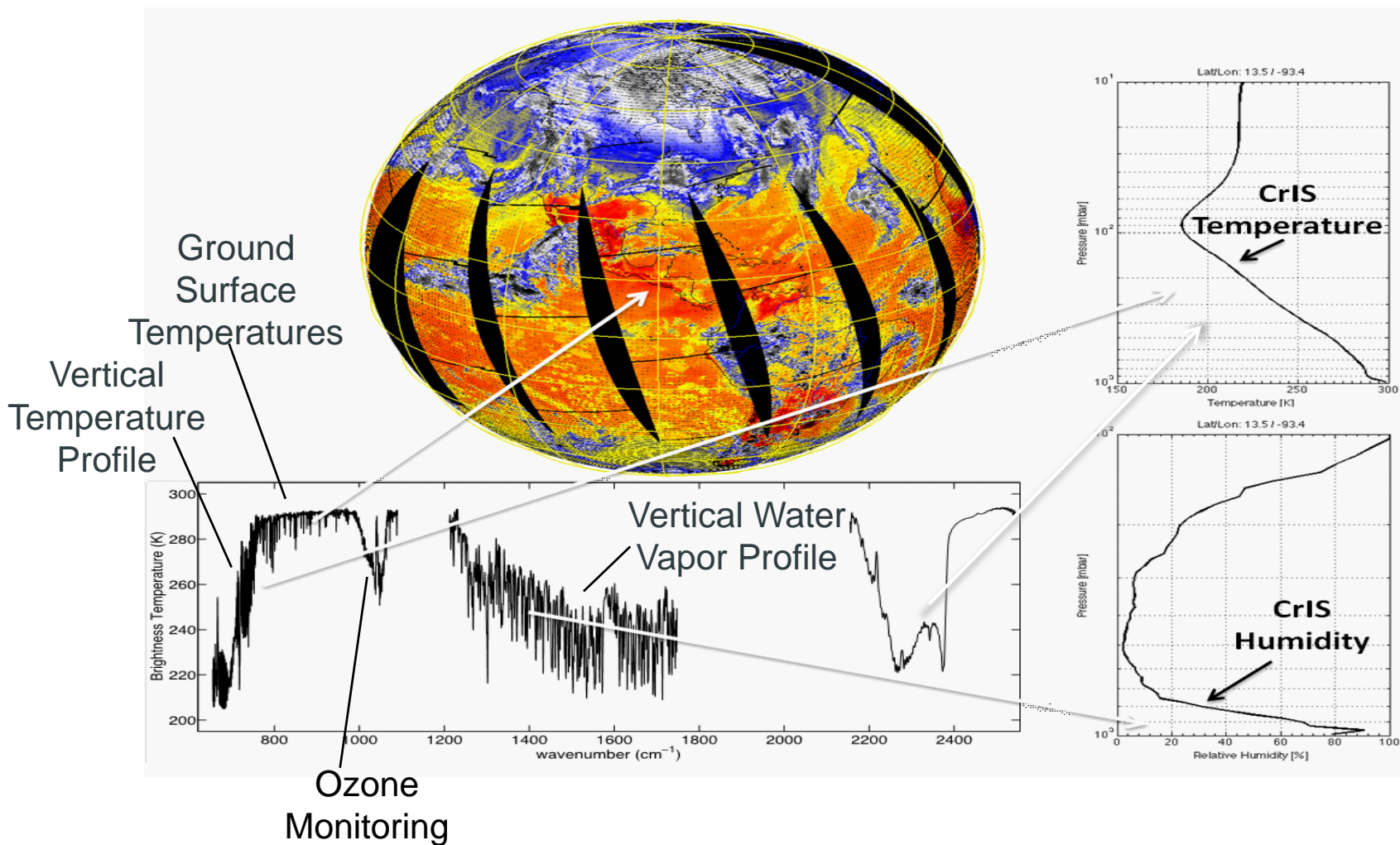


*Ensemble of CrIS Data Collected During a Typical 2-Day Period in May 2012*



*Each Pixel Contains Over 2000 Spectral Channels Across 3 Bands*

# CrIS Data Products Provide Critical Inputs to Global Weather Predictions





# CrIS SNPP Status: Launched in 2011



## Over 6 years in orbit

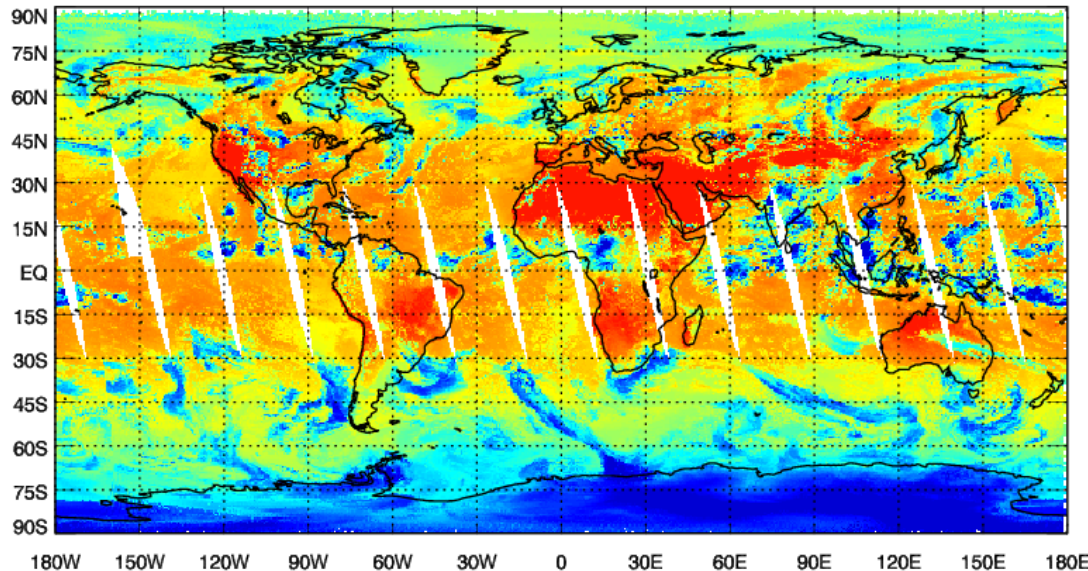
- Approaching required lifetime of 7 years

## Excellent radiometric performance

- Very stable throughout mission life

## Full spectral resolution test mode became baseline after launch

NPP CrIS Brightness Temperature,  $11\ \mu\text{m}$  ( $900\ \text{cm}^{-1}$ ), Mapped, Ascending, 07/26/2016  
Updated at Jul 27 10:55:01 2016 UTC



**CrIS Continues to  
Provide Critical Inputs  
to Global Weather  
Forecast Models**



# Improvements for CrIS JPSS-1



## Improved Internal Calibration Target

- Higher emissivity, more tightly calibrated temperature sensors

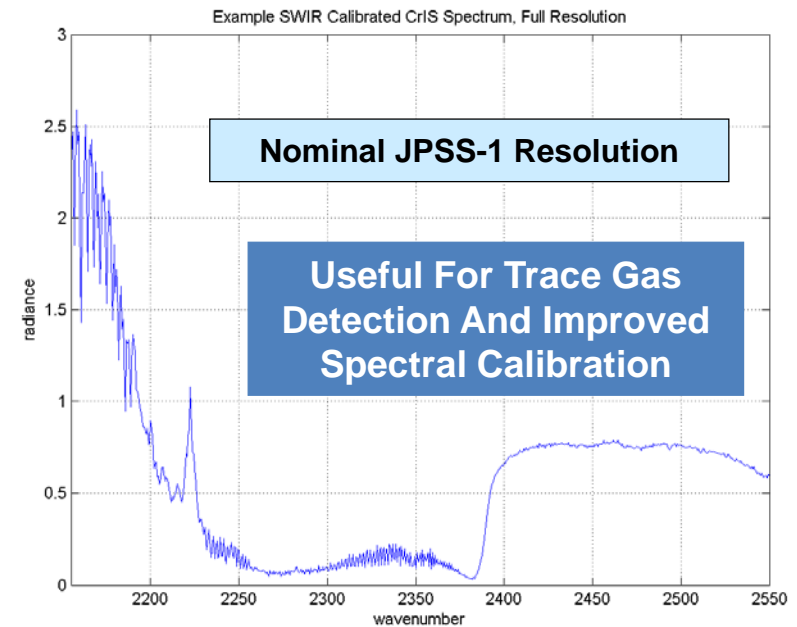
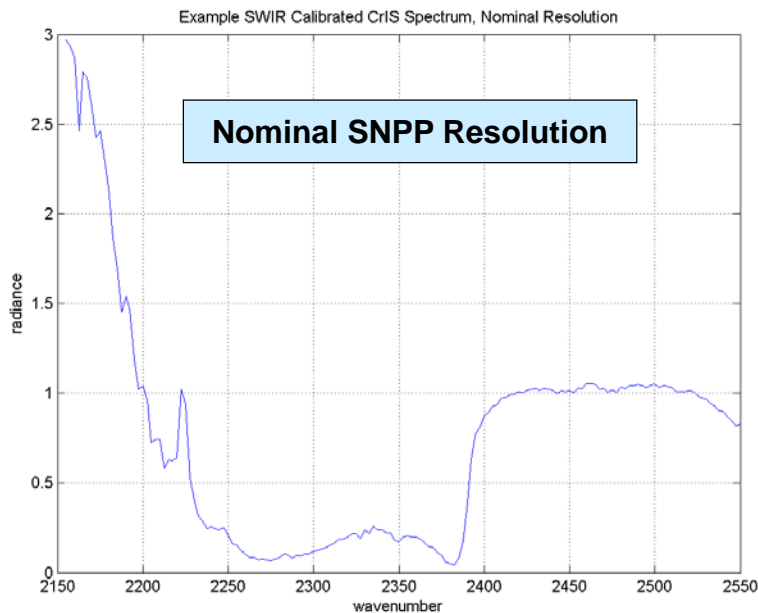
## Several incremental improvements from SNPP lessons learned

- Structure, electronics boards, various modules

## Full spectral resolution is now nominal mode



New Specular-Trap  
Internal Calibration Target



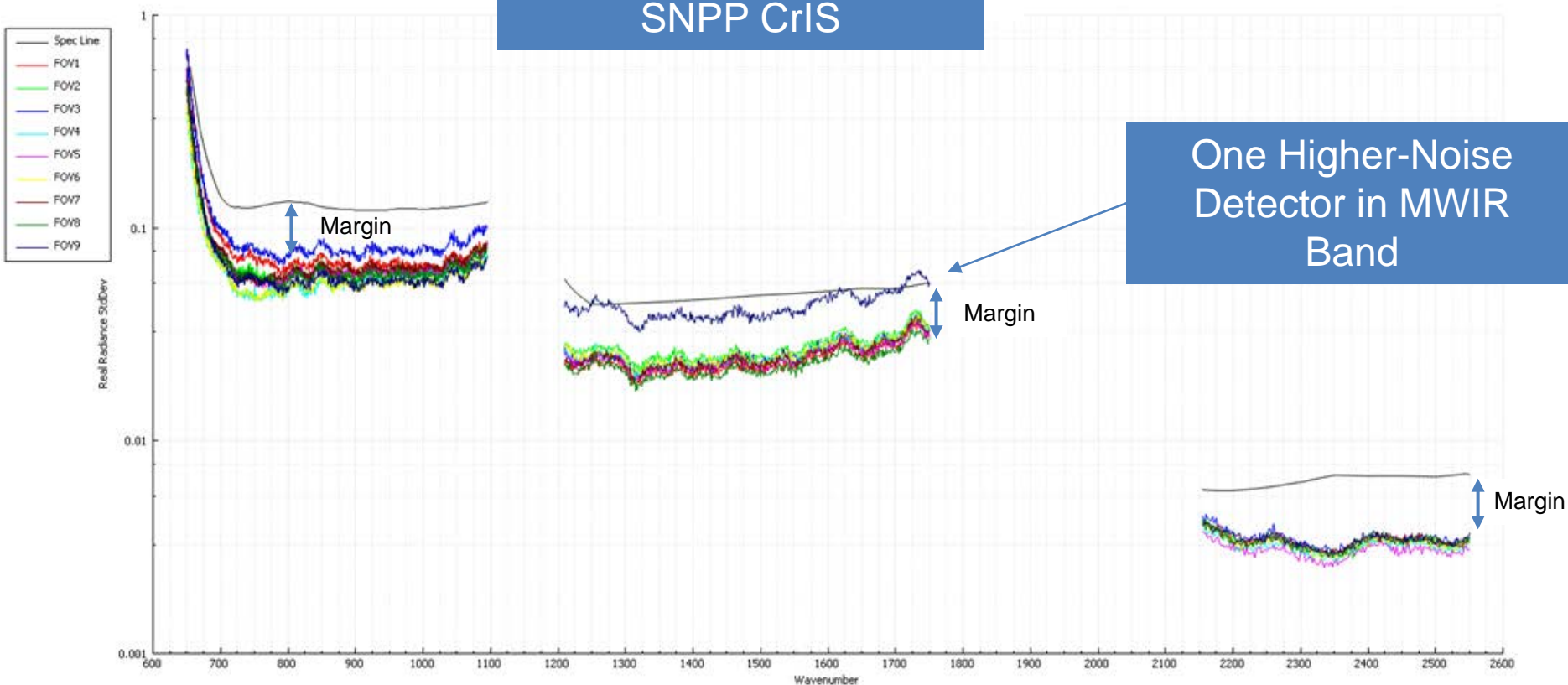
**Four key performance parameters directly impact the quality of temperature and moisture soundings**

- **Noise Equivalent Spectral Radiance (NEdN)**
- **Absolute Radiometric Uncertainty**
- **Radiometric Repeatability (short- and long-term stability)**
- **Spectral Stability**

# JPSS-1 NEdN Meets Specification With Margin



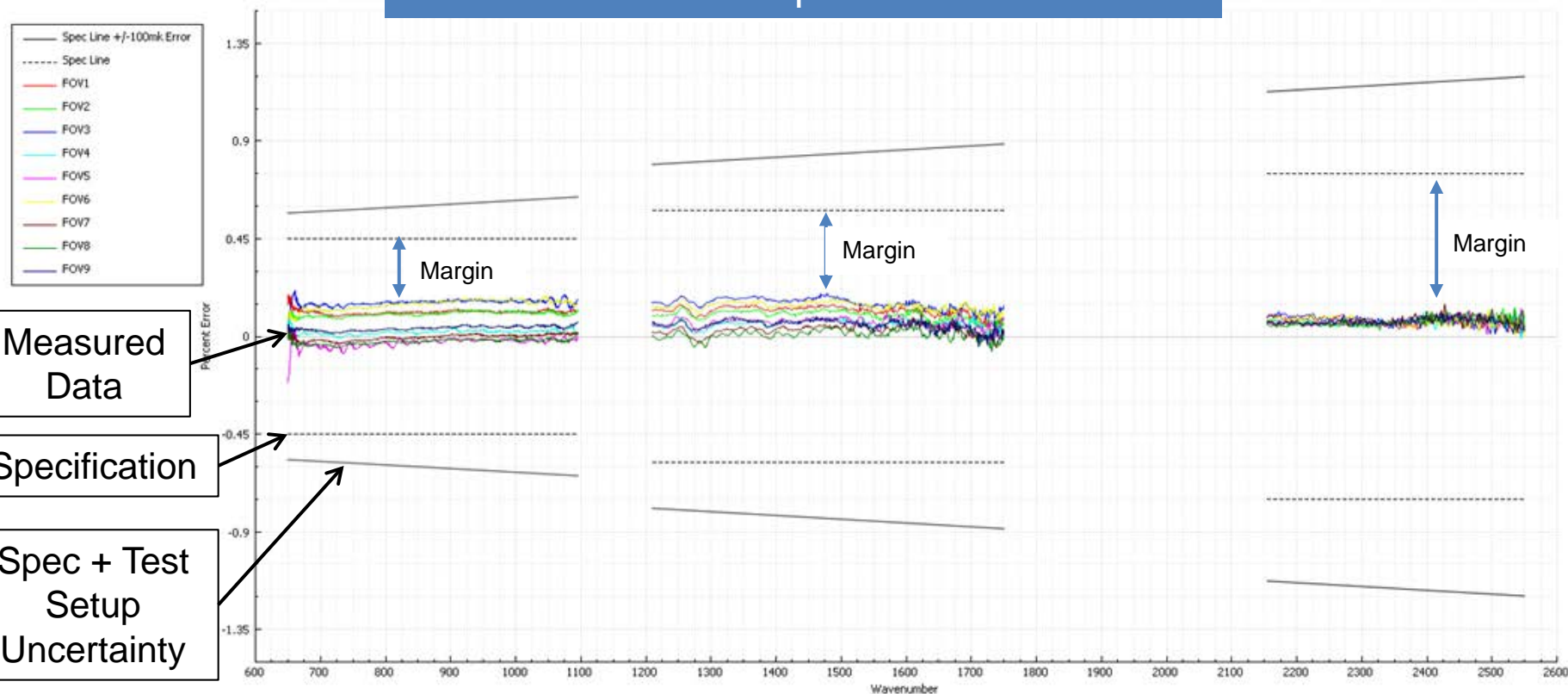
JPSS-1 NEdNs are  
Slightly Better Than  
SNPP CrIS



# Calibration Accuracy Demonstrated During Testing

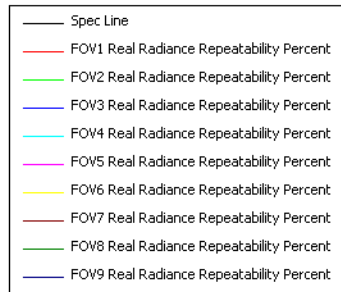


Absolute Accuracy <150mK, or >3X Better Than Requirements

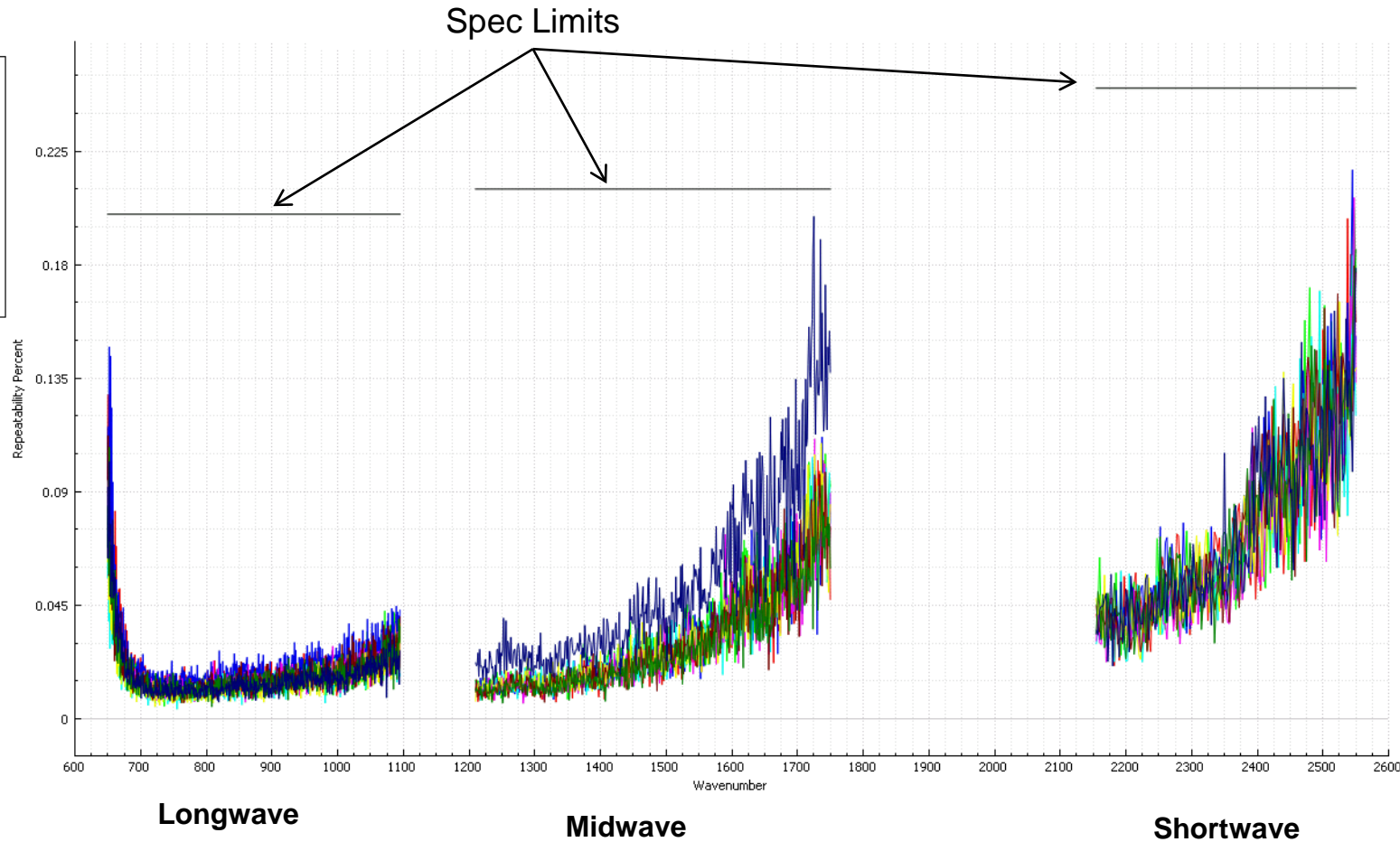




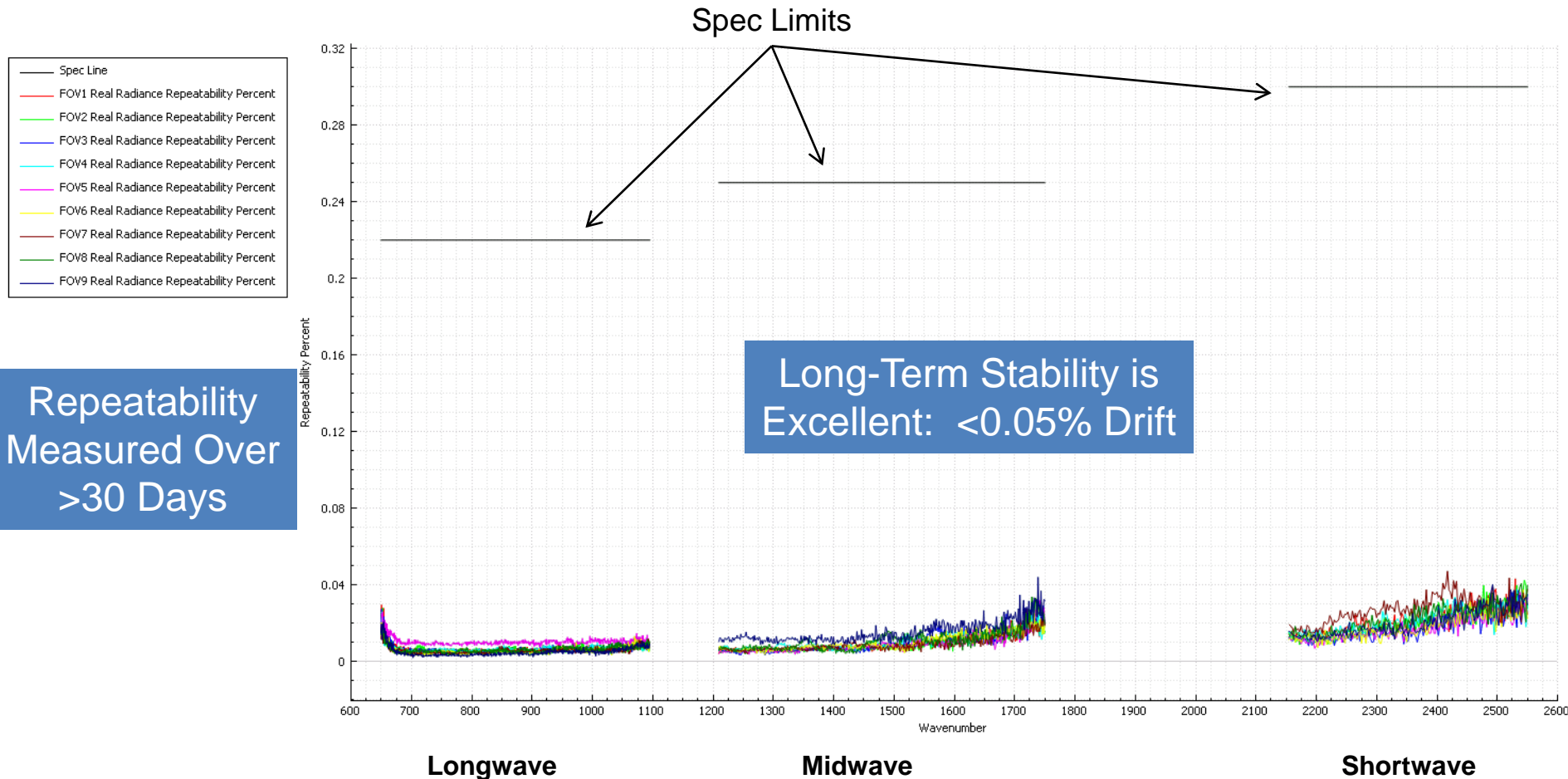
# Short-Term Repeatability Well Within Spec Limits



Repeatability  
Measured  
Over 1 Hour



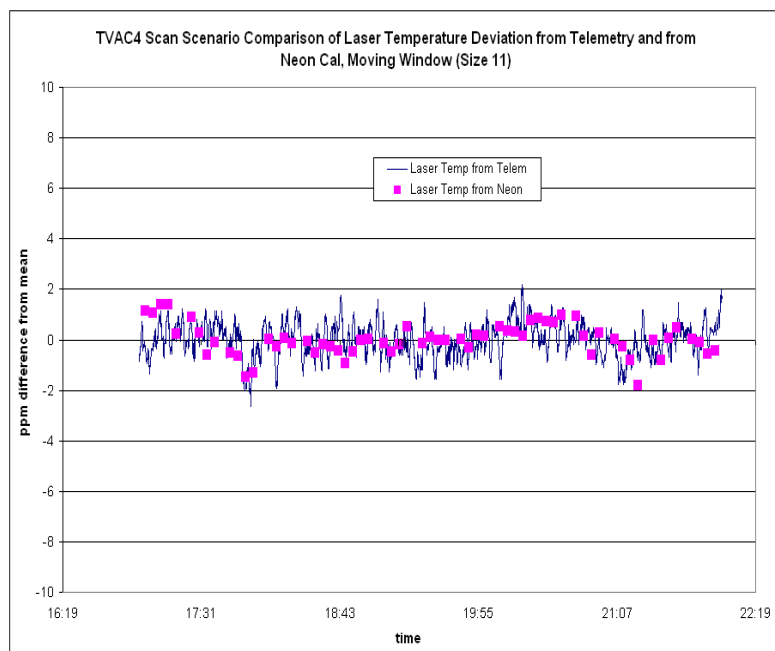
# Long-Term Repeatability is Outstanding



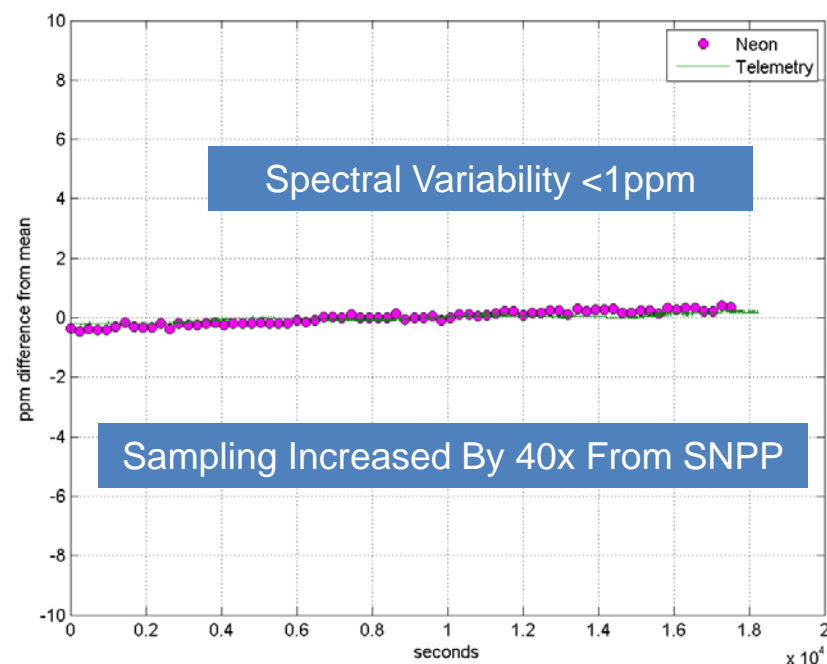
# JPSS-1 Spectral Stability is Even Better Than SNPP



## SNPP



## J1



JPSS-1 Performance Improved by ~10x From SNPP;  
Expected to Provide Improved Spectral Accuracy On-Orbit

# CrIS JPSS-1 On-Orbit Status



**JPSS-1 was successfully launched on November 18, 2017**

**CrIS successfully powered up in early December**

- Placed in outgas mode to ensure contaminants do not collect on passive cooler surfaces or cold detectors
- On-orbit telemetry shows as-expected temperature variations

**Plan to reach CrIS operational status:**

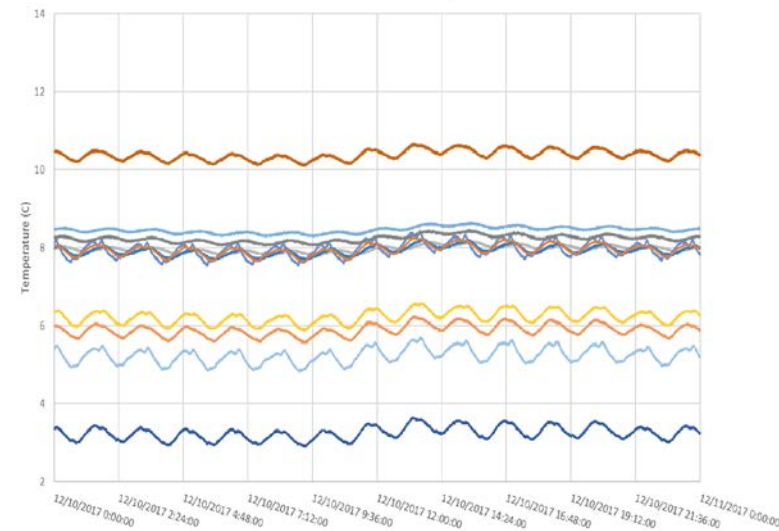
- L+45 (1/02/2018) Release Cooler Cover
- L+48 (1/05/2018) Power on Detectors
- ~L+90 (3/2018) Provisional Maturity
- ~L+270 (8/2018) Operational Maturity



*JPSS-1 Launch*



*Satellite Deployment*

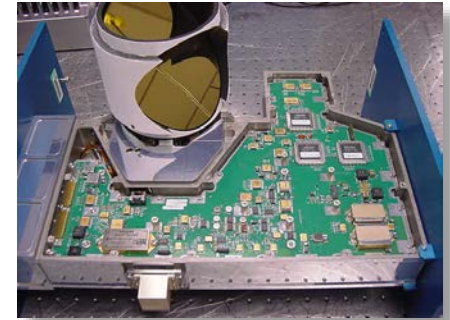


*Temperatures Throughout the CrIS Instrument Show Small Temperature Variations in Sync With Orbital Period*



## CrIS for JPSS-2

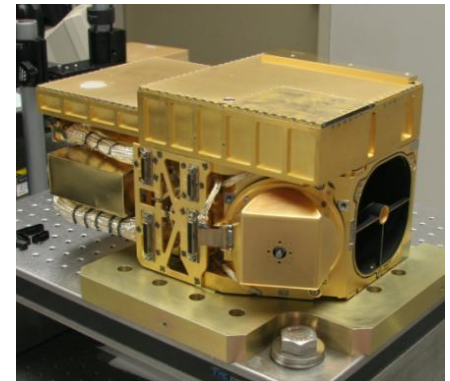
- Most modules complete and ready for integration
- Co-registration successfully completed
- Environmental testing begins later this year
- Delivery planned for 2019



CrIS Scanner Module for JPSS-2

## CrIS for JPSS-3

- In Assembly: Aft Optics, Earth Shield, Detector Cooler, Scanner, Cal Target, Interferometer, Electronics, Frame
- In Manufacturing: Optical Bench, Telescope, Vibration Isolation System
- Delivery planned for 2020



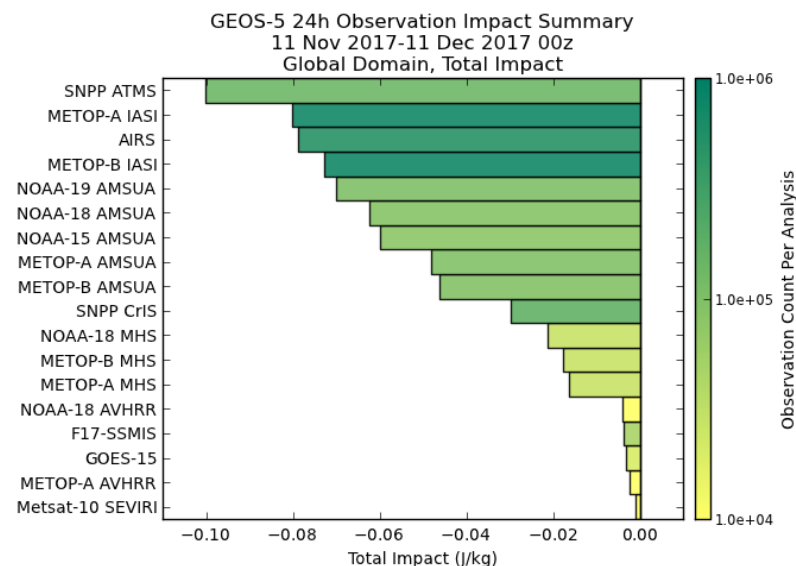
CrIS Interferometer for JPSS-2

## CrIS for JPSS-4

- 97% of parts on order
- Module builds are underway
- Delivery planned for 2021

## Hyperspectral sounding data assimilation history is international research-to-operations success story

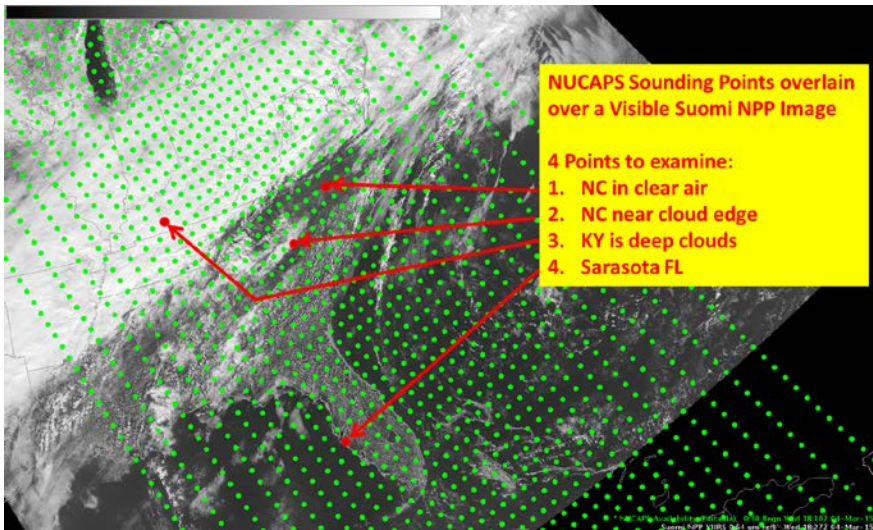
- Multi-spectral Soundings (1969 – 2012)
- Radiance assimilation techniques, ca. 1990s
- Establishment of multi-agency *Joint Center for Satellite Data Assimilation* to address backlog of data and accelerate utilization of new sensor data (ca. 2001-2002)
- Series of polar hyperspectral infrared sounders demonstrate significant forecast impact as most important measurement due to improved resolution
  - NASA AIRS (launch 2002, assimilation ca. 2003 - 2004)
  - EUMETSAT IASI (launches in 2006, 2011)
  - Suomi-NPP CrIS (launched in 2011)
- Continuity of US polar operational hyperspectral sounding capability initiated with the second CrIS instrument launched on JPSS-1, 2017



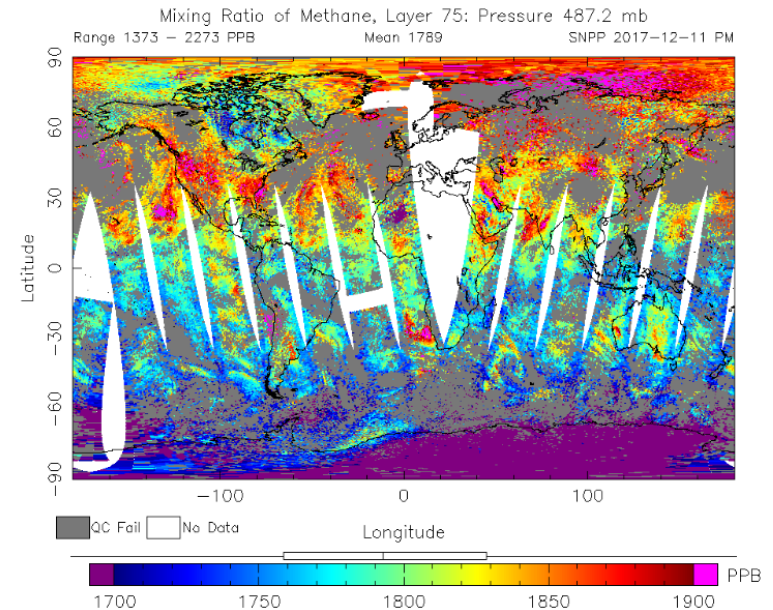
## Environmental Data Products from hyperspectral sounders support new applications

- Temperature, water vapor, cloud fraction and cloud top pressure, ozone (O<sub>3</sub>), methane (CH<sub>4</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (N<sub>2</sub>O), and nitric acid (HNO<sub>3</sub>), and presence of dust and volcano emission

**NOAA Unique Combined Atmospheric Processing System (NUCAPS) and distribution through AWIPS-II provides significantly more satellite-derived soundings to forecast offices in regions of interest for improving forecast guidance (B. Motta, NOAA/NWS)**



- Constructing consistency among AIRS/IASI/CrIS for multi-decadal record of hyperspectral data will enable climate studies of atmospheric constituents



## **Deploy smaller platforms to fill high-priority observing gaps**

- Hypercube 3D Wind profiles

## **Extend to geostationary hyperspectral sounding capability for faster updates of horizontal and vertical water vapor and temperature structures**

- 3-dimensional spatial and temporal continuity of observations needed for next significant improvements in short-term weather forecasting
- Geostationary Interferometric Infrared Sounder (GIIRS), China, 2016

## **Utilize more data from existing instruments**

- Cloudy radiances
- Additional channels and new channel selection approaches
- Consideration of direct sounding assimilation
- Two operational US CrIS instruments separated by about one hour

## **Understand observing system impacts on Numerical Weather Prediction for next-generation instrument and constellation design**

“Forecast sensitivity to observation” inter-comparison studies compare data assimilation systems at major weather centers and improve interpretation of hyperspectral sounding impact statistics



## **Better spatial resolution**

- Fidelity of weather forecast models continue to improve
- Higher probability of cloud-free soundings
- Better mapping of trace gas sources and sinks

## **Better spectral resolution**

- More utility for trace gas monitoring

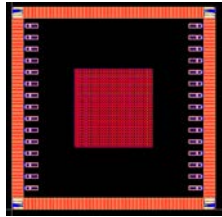
## **More frequent updates**

- More frequent data model ingests possible
- Especially for finer-scale models

## **Lower Cost**

Correlated: Lower cost  
enables more sounders  
which enables more  
frequent updates

# New Technologies to Enable Future IR Sounders



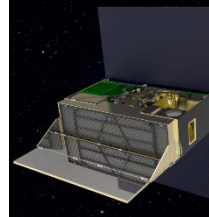
**25x25 High-Speed  
IR FPA**



**Extreme Onboard  
Processing**



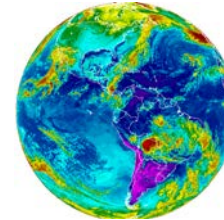
**HyperCube  
Stratospheric  
Platform Test**



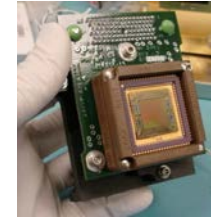
**HyperCube  
Flight Demo  
(2020)**



**HarrisSat SmallSat  
Control Facility**



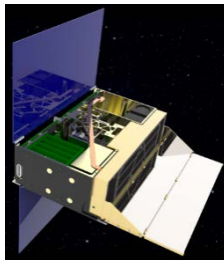
**Hyperspectral  
Ground  
Processing**



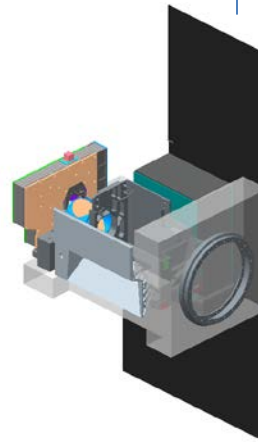
**96x96 High-Speed  
FPAs**



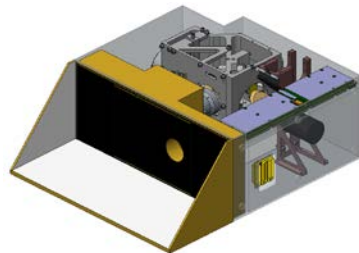
**Interferometer  
Systems for  
GEO**



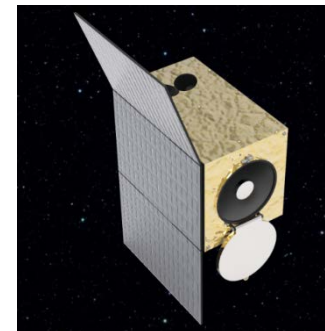
**MWIR CubeSat  
Sounders in 6U  
CubeSats**



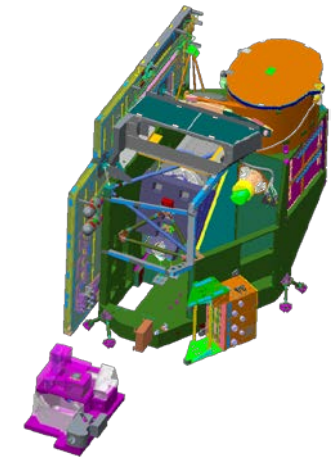
**CrIS Free-Flyer in  
ESPA Ride Share**



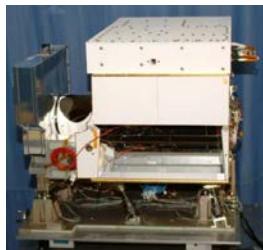
**LWIR CubeSat Sounders  
in 12U CubeSats**



**Large-Aperture  
Hyperspectral  
SmallSats**



**ABI-Based  
Hyperspectral  
Sounder in GEO  
(High Temporal)**



**CrIS With 2 km  
Spatial Resolution**

- **CrIS on JPSS-1 will continue to provide high-quality temperature and moisture soundings vital to weather forecasting**
- **CrIS JPSS-1 performance is as good or better than CrIS SNPP**
- **Three more CrIS instruments are in production**
- **New technologies are enabling improved IR sounders for the future**
  - Smaller instruments and platforms to fill high-priority observing gaps
  - Extend to geostationary hyperspectral sounding capability